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The Technology Study of Fuzzy Control System for Permanent Magnet Brushless DC Motor*

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Abstract: According to the Y-connected three-phase full-controlled bridge between two turn-on circuit, the paper studies the working principle and builds the mathematical model of permanent magnet brushless DC motor(BLDCM). Then the paper introduces fuzzy control technology, and designs the fuzzy control system of permanent magnet BLDCM, at the same time, the paper makes simulation in Matlab/Simulink. Being different from the conventional PID control system, the fuzzy control system of BLDCM can enhance the anti-interference ability of the outside environment, and the fuzzy control system can also reduce significantly torque ripple of BLDCM. Therefore, the fuzzy control technology is introduced in the application of permanent magnet BLDCM, and provides a very idea to the application of BLDCM for the majority of the scientific and technical workers.

Keywords: permanent magnet BLDCM; fuzzy control; anti-interference; torque ripple; simulation

1. INTRODUCTION

With the continuous development of industrial and agricultural production, the speed, torque and the elimination of interference in the increasingly high performance are requested more and more high for the permanent magnet brushless DC motor（BLDCM）[1]. In the usual case, the control system design of BLDCM uses the traditional PID control, and the PID control has the advantages of simple structure, good stability, high reliability characteristics. When BLDCM is established the precise mathematical model of control object, the control system of BLDCM can set the correct parameters Kp, Ki and Kd, and PID controller can realize its function. But the design of motor exists in the dynamic response time and overshoot of the technical indicators of difficult. At the same time, because the motor exists non-linear and time-varying, and other uncertain factors, the effect of PID control is difficult to achieve the desired objectives. That is to say, the PID controller for different controlled objects with different PID parameters, and the adjustment is inconvenient, and poor anti-interference ability. In the other hand, the fuzzy control is a control language, and does not depend on the object's mathematical model, and the design method is simple, and also the control strategy is easy to implement. The fuzzy control can directly get from the experience of the operator, and obtain optimal induction, adaptation ability, strong anti-interference ability and good robustness[2,3]. The paper designs the fuzzy control system for permanent magnet BLDCM, and carries on the simulation on Matlab/Simulink. The simulation results show that the BLDCM with fuzzy control has better performance than the traditional PID control.

2. THE MATHEMATICAL MODEL OF PERMANENT MAGNET BLDCM

In order to facilitate analysis, the following assumptions is: (1) The three-phase winding is completely symmetrical. Air-gap magnetic field is a square wave. Stator current and rotor magnetic field are distributed for the symmetric. (2) Ignoring the alveolar, commutation and armature reaction and so on. (3) The armature winding is continuous uniform distribution on the inner surface of the stator. (4) The magnetic circuit is unsaturated, and it doesn't consider the eddy current and hysteresis losses. Thus the three-phase winding voltage balance equation can be expressed as[4]:

$$\begin{bmatrix} u_a \\ u_b \\ u_c \end{bmatrix} = \begin{bmatrix} R_a & 0 & 0 \\ 0 & R_b & 0 \\ 0 & 0 & R_c \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \begin{bmatrix} L_a & M_{ab} & M_{ac} \\ M_{ba} & L_b & M_{bc} \\ M_{ca} & M_{cb} & L_c \end{bmatrix} p \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \begin{bmatrix} e_a \\ e_b \\ e_c \end{bmatrix} + U_n \begin{bmatrix} 1 \\ 1 \\ 1 \end{bmatrix} \tag{1}$$

Where: u_a、u_b、u_c — the stator winding phase voltage (V);

R_a、R_b、R_c —the stator winding resistance (Ω);

i_a、i_b、i_c —the stator winding phase current (A);

e_a、e_b、e_c —the stator winding back EMF (V);

L_a、L_b、L_c —self-inductance (H);

M_{ab}、M_{ac}、M_{cb} —mutual-inductor (H);

There are $R_a=R_b=R_c=R$、$L_a=L_b=L_c$、$M_{ab}=M_{ac}=\cdots=M_{cb}=M$ from the above assuming. When the three-phase winding is star connected and there is no neutral connection, there are $i_a=i_b=i_c$. So the equation (1) can be written as:

$$\begin{bmatrix} u_a \\ u_b \\ u_c \end{bmatrix} = \begin{bmatrix} R & 0 & 0 \\ 0 & R & 0 \\ 0 & 0 & R \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \begin{bmatrix} L-M & 0 & 0 \\ 0 & L-M & 0 \\ 0 & 0 & L-M \end{bmatrix} p \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \begin{bmatrix} e_a \\ e_b \\ e_c \end{bmatrix} + U_n \begin{bmatrix} 1 \\ 1 \\ 1 \end{bmatrix} \quad (2)$$

The expression of electromagnetic torque produced by the stator windings is[6]

$$T_e = \frac{1}{w}(e_a i_a + e_b i_b + e_c i_c) \quad (3)$$

Equation of motion of the motor expression is:

$$T_e - T_L - Bw = J\frac{dw}{dt} = Jpw \quad (4)$$

where: T_e—the magnetic torque $(N \cdot m)$;

T_L—the load torque $(N \cdot m)$;

B—the damping factor $(N \cdot m \cdot s / rad)$;

ω—the motor speed (rad / s);

J—the motor moment of inertia (kg / m)

3. THE DESIGN OF FUZZY CONTROL SYSTEM FOR PERMANENT MAGNET BLDCM

3.1. The structure of fuzzy control system for permanent magnet BLDCM

The structure diagram of fuzzy control for permanent magnet BLDCM is shown as Figure1, and it is the direct implementation of fuzzy reasoning algorithm for fuzzy control system. The fuzzy controller is the core part of fuzzy control system for BLDCM, and it composed of fuzzy, fuzzy inference and fuzzy solution [5].

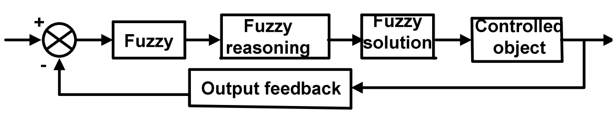


Figure1. The structure of fuzzy controller

In the fuzzy controller, the number of input variables is usually called the dimension of fuzzy controller. According to the number of input variables, the fuzzy controller can be defined as one-dimensional fuzzy controller, two-dimensional fuzzy controller and three-dimensional fuzzy controller. The dimension of fuzzy controller is higher, and the control precision is better, but due to the structure of three-dimensional fuzzy controller is too complex, and the inference and operation time is long, and fuzzy controller leads controller design difficulty, high demand for hardware, and difficulties in application. In order to solve the problem, the paper adopts double-input fuzzy controller with separation of the integration, and the principle diagram is shown as Figure2. According to the actual situation can be specific control integral effect size by adding programmable integrator, and in the control process of the early time, the fuzzy controller reduces the integral role of the system to avoid excessive overshoot and fast response speed. At the same time, in the control process of the late time increases the integral action, and in order to ensure the system control precision. So the controller not only has all the advantages of three-input fuzzy controller, but also has the advantage of inference operation relatively short time.

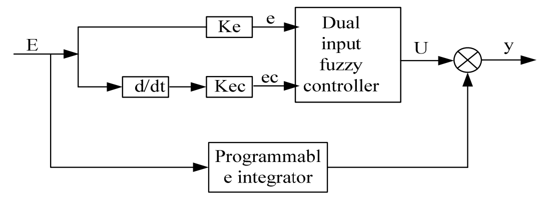


Figure2. The principle diagram of double input fuzzy controller

3.2. The fuzzy design of fuzzy controller

On error, error rate of change and control of the amount of fuzzy sets and theory domain is defined as follows:
Fuzzy set of is : {NB, NM, NS, ZO, PS, PM, PB};
Fuzzy set of is: {NB, NM, NS, ZO, PS, PM, PB};
Fuzzy set of is: {NB, NM, NS, ZO, PS, PM, PB};
The field of and are: (3, 3);
The field of is: (- 6, 6).
The membership function graphics are shown as Figure 3, figure 4, and figure 5.

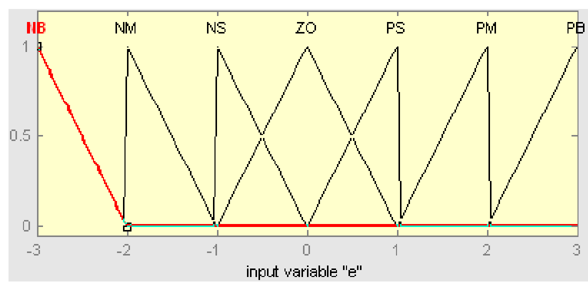


Figure3. The membership functions of the error e

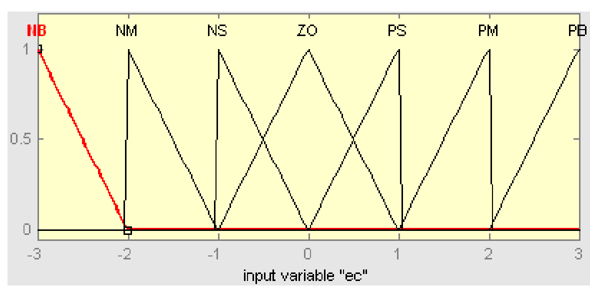


Figure4. The membership functions of the error rate ec

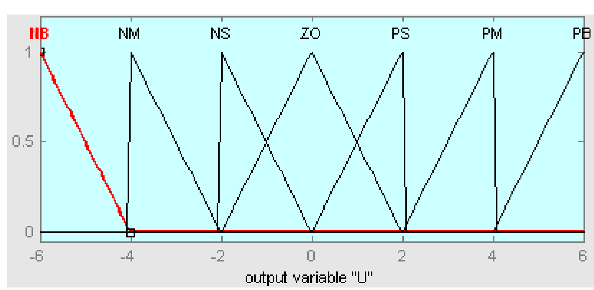


Figure5. The membership functions of the control quantity U

The rule base of the fuzzy controller is established according to the on-site operation of the control experience and expert knowledge, and the rule base is shown as table1.

Table1. The fuzzy controller rule library

ec \ U (e)	NB	NM	NS	ZO	PS	PM	PB
NB	NB	NB	NM	NM	PM	PB	PB
NM	NB	NM	NS	NS	PS	PM	PB
NS	NB	NM	NS	NS	PS	PM	PB
ZO	NB	NM	NS	ZO	PS	PM	PB
PS	NB	NM	ZO	PS	PS	PM	PB
PM	NB	NM	PS	PS	PM	PB	PB
PB	NM	NS	PM	PM	PM	PB	PB

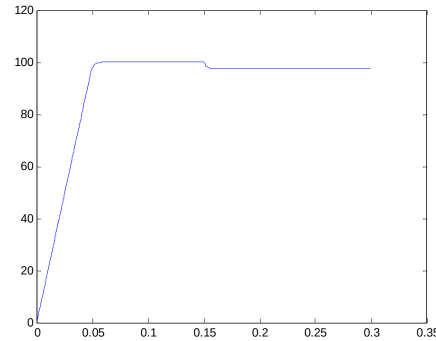
4. The SIMULATION RESULTS AND ANALYSIS OF THE FUZZY CONTROL SYSTEM FOR PERMANENT MAGNET BLDCM BASED ON MATLAB

4.1. The simulation parameters setting of the permanent magnet BLDCM

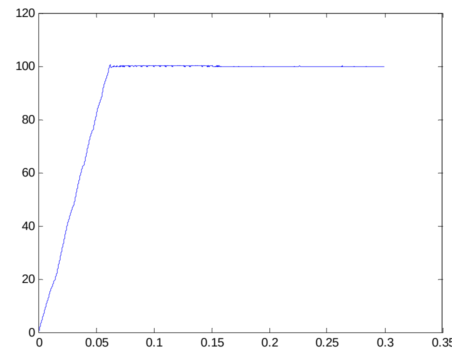
The motor parameters: the rated speed $n_N = 100rpm$; the stator winding resistance $R = 1.464m\Omega$; phse inductance $L = 13.5\mu H$; opposite electromotive force $C_e = 0.006V \cdot s / rad$; motor pole pairs $p = 3$; rated voltage of 220V; the given angular speed $\omega = 100 rad / s$.

4.2. The analysis of simulation results

According to the above analysis, the paper builds PID double-closed loop control system and fuzzy control PID control system respectively in the Matlab/Simulink for the permanent magnet BLDCM[6,7,8,9], and the simulation results is shown as Figure6 and figure7. The speed simulation waveform of PID control and fuzzy control is shown as (a) and (b) of Figure6. The simulation waveform of the speed response with PID control is in the figure 6(a), and the simulation waveform of speed response with fuzzy control is in the figure 6(b). It is easy to see that the anti-interference of fuzzy control is significantly stronger than the traditional PID control from the simulation waveforms, and the speed waveform with fuzzy control has almost no effect when load is set in the t = 0.15s moment, but the speed waveform with PID control has significant jitter. The torque simulation waveform of PID control and fuzzy control is shown as (a) and (b) of Figure7. The simulation waveform of the torque response with PID control is in the figure 7(a), and the simulation waveform of torque response with fuzzy control is in the figure 7(b). It is easy to see that the torque ripple of fuzzy control is significantly smaller than the traditional PID control torque pulsation. Therefore the fuzzy control is applied to the design of control system for the permanent magnet BLDCM, and motor performance is superior to the traditional PID control.

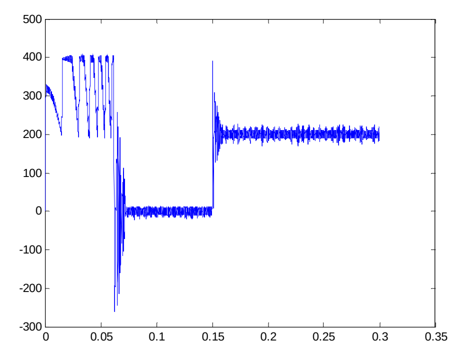


(a) The speed response curve using PID control system

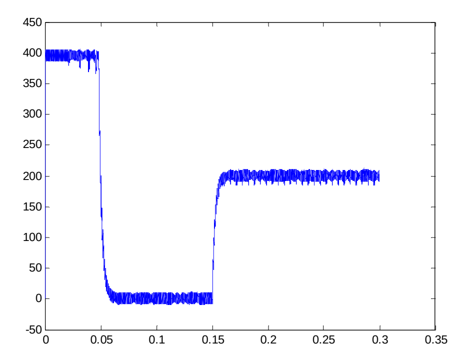


(b) The speed response curve using fuzzy control system

Figure6. The simulation waveforms of the rotating speed of BLDCM based on PID and fuzzy control



(a) The response curve of torque pulse using PID control system



(b) The response curve of torque pulse using fuzzy control system

Figure7. The simulation waveforms of the torque ripple of BLDCM based on PID and fuzzy control

5. CONCLUSION

Based on the mathematical model of permanent magnet BLDCM, the paper introduces the fuzzy control into the control system of BLDCM. Compared with the traditional double-loop PID control system, the permanent magnet BLDCM of the fuzzy control system has better performance, especially its anti-interference enhancement.

6. ACKNOWLEDGEMENTS

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